A MULTI-SENSOR FUSION TRACK SOLUTION TO ADDRESS THE MULTI-TARGET PROBLEM

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(1) ABSTRACT:

In close-in air combat and in tactical air reconnaissance and surveillance environment, there are multiple sensors and multiple targets involved. To keep track of all tactical targets in such an environment is clearly a multi-sensor track fusion problem. Currently, one of the widely used multi-sensor fusion trackers is the Extended Kalman Tracker (EKT). In a multisensor-multitarget position estimation problem, the key issue is data association which consists of associating measurements from a number of sensors. The numerical complexity of the data association problem becomes an exponential in nature as opposed to a polynomial, when the number of sensors is greater than 3. Furthermore, in a dense target environment with maneuvering targets, the association problem becomes more complex, which equates to more computer power and memory resources.

The Gating model, the position vector update, and the covariance matrix updates are all required for matrix inversion for every sensor measurement in the EKT. This matrix inversion uses a lot of computational time and mission computer memory especially when operating in a dense target environment. The target position accuracy, the velocity, and other target parameter estimations, may be affected due to the computational time and compute memory limitations. This multi-target and multi-sensor track fusion problem needs to be addressed for future airborne strike and surveillance platforms and Global Position System.

A multi-sensor correlation processor with an α, β, γ tracker is introduced as the multi-sensor fusion track model to address the multi-target and maneuvering targets. The new system requires no algorithmic matrix inversion and can be proven to be mathematically equivalent to the popular multi-sensor fusion track model in accuracy. The new multi-sensor fusion track model consists of the sensors, I/O parameter transformation processor, multi-sensor correlation processor, the α, β, γ tracker, and the operator and platform Interface unit.

We believe that this solution is easy in algorithmic implementation, and can provide reduced computational time and computer memory by avoiding matrix inversion. The new multi-sensor fusion track system should be considered as an applied fusion model to solve the real time multi-target problem.

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(2) INTRODUCTION:

The existing extended Kalman track fusion model, has the following major components:

- **(a) Gating Algorithm**
- **(b) Position update algorithm**
- **(c) Covariance matrix update algorithm**

It is computationally intense. Every sensor measurement requires matrix inversion. It is too slow for tracking the fast target in a Multi-sensor and multiple target environment. Therefore the existing track fusion model needs improvement.

The objective of this paper is to devise a means to minimize the computational steps and increase tracking speed for the fast targets. A modified Multi-sensor track fusion model is introduced, to solve some of the Multi-sensor track fusion problems. The practical ways to solve the matrix inversion in the existing extended Kalman track fusion model are:

- **(a) Replacement of the gating algorithm.**
- **(b) Replacement of the position update algorithm.**
- **(c) Replacement of the covariance update algorithm.**

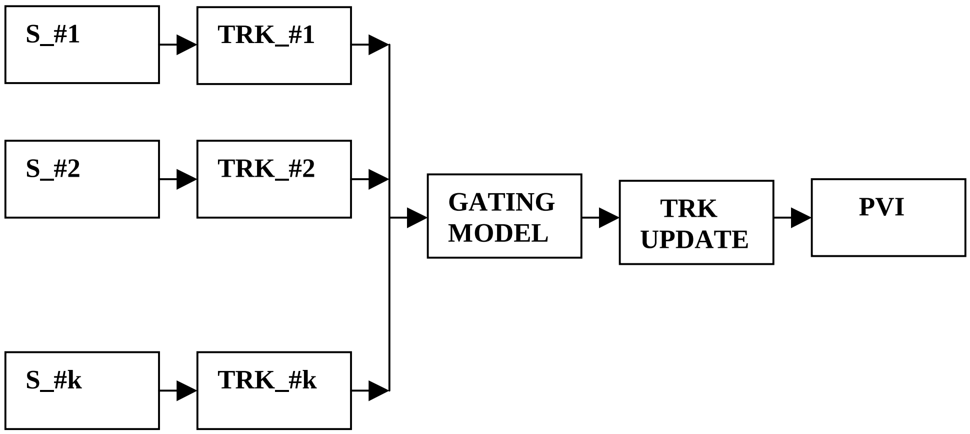
With these replacements, all matrix inversion is completely eliminated.

The new replaced algorithms will formulate the new modified multi-sensor Track fusion model. The new equations in the modified multi-sensor track fusion Are:

(a) The Multi-sensor correlation processor, which is used to estimate the relationship between two target vectors, performs a function similar to the gating algorithm in the existing extended Kalman track fusion model. The gating algorithm requires matrix inversion for every sensor measurement, whereas, the Multi-sensor correlation processor does not require matrix inversion for every sensor measurement.

(b) The α, β, γ Tracker which replaces the Extended Kalman Tracker position update algorithm and the covariance update algorithm Model requires no matrix inversion for every sensor measurement, whereas the Extended Kalman Track fusion model does.

(3) THE EXISTING EXTENDED KALMAN TRACK FUSION MODEL:



(A) GATING ALGORITHM:

$$G = (Z - H*X_k)^T * \{ H*P*H^T + R)^{-1} * (Z - H*X_k)$$

(B) POSITION UPDATE ALGORITHM:

$$X_{k+1} = X_k + G * (Z - H * X_k)$$

(C) COVARIANCE MATRIX UPDATE ALGORITHM:

$$P_{k+1} = P_k * (I - G*H)$$

Tracking processing:

(a) Sensor measurements are obtained from the "Sensor" unit, preprocessing for target feature vectors.

(b) Target feature vector is passed on to the "TRK_#k" unit as input vector for target track estimation.

(c) Target tracks are passed on to the "Gating Model" unit for track to track correletion, and the distinct uncorrelated target tracks are sent to "TRK UPDATE" unit using Extended Kalman Tracker For track position update and target covariance update.

(d) The updated target tracks are pass to PVI unit to build the central track file (CTF), in which the Pilot will get the Multi-sensor fused target tracks.

Equations (A) , (B) and (C) indicate a matrix inversion calculation for each sensor measurement, which will slow down the total tracking process and degrade the track accuracy.

(4) THE GATING MODEL:

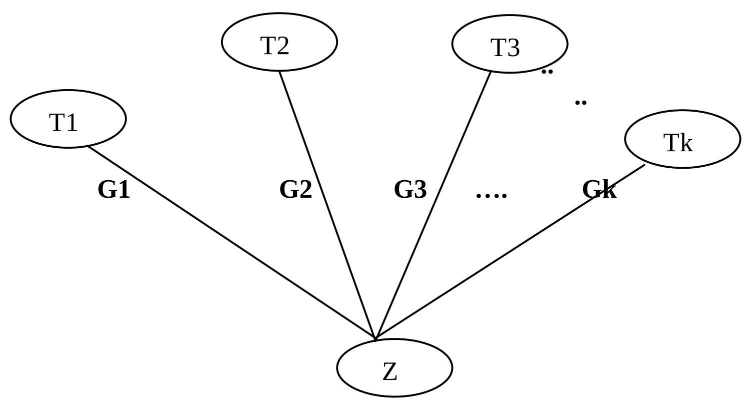
The Gating Model is one of the important elements of the existing Multi-sensor track fusion model. The gating model sometime is also known as the Chi Square Test. The Gating model can be expressed mathematically as follows:

$$G(Z) = (Z - H * X_k)^T * INV\{ \Sigma \} * (Z - H * X_k)$$

Where $\Sigma = (H * P_k * H^T + R)$

Z = **Sensor Measurement Vector**
X_k = **Target State vector at time k**
P_k = **Target State Covariance Matrix at time k**
H = **Jacobian Matrix**
Σ = **Residue Covariance Matrix**

Graphically, the Gating model can be interpreted as :



Decision Rule:

If $G_k (z) = MIN \{ G_i(z) \}$

Then $z \subset k$ **th Target**

Where z is the sensor measurement vector and $G_k(z)$ **is the k th Gating Value. The gating value is very reliable and provides accurate decision, but is computationally very slow, because matrix inversion is needed for every sensor measurement.**

(5) THE EXTENDED KALMAN TRACKER MODEL:

Mathematically, the Extended Kalman Tracker model can be defined as follows:

(a) PROPAGATING STATE VECTOR:

$$X_k = \Phi * X_{k-1} + U$$

(b) PROPAGATING STATE COV MATRIX:

$$P_k = \Phi * P_{k-1} * \Phi^T + Q$$

(c) KALMAN GAIN MATRIX:

$$K = P_k * H^T * INV\{ H * P_k * H^T + R \}$$

(d) GATING ALGORITHM:

$$G = (Z-H*X_k)^T * \{ H*P*H^T + R)^{-1} * (Z - H*X_k)$$

(e) UPDATE STATE COV MATRIX:

$$P_{k+1} = P_k * (I - G*H)$$

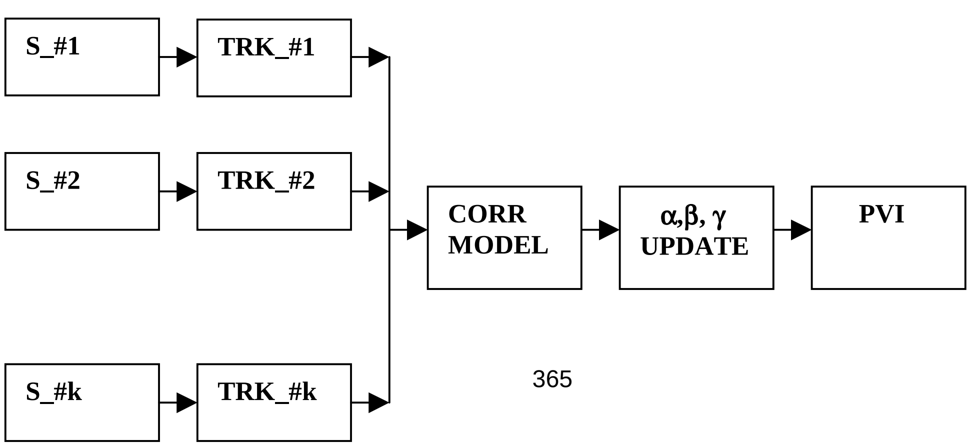
(f) UPDATE STATE VECTOR:

$$X_{k+1} = X_k + G * (Z - H * X_k)$$

Where U = Noise Vector
Φ = Transition Matrix
Q = Noise Cov Matrix
R = Measurement Noise Matrix
X_k = State Vector at time k
P_k = State Cov Matrix at time k
H = Jacobian Matrix
G = Gating Matrix
K = Kalman Gain Matrix
Z = Measurement vector

The Extended Kalman Tracker is one of the widely used trackers, Its track accuracy is very good, but equations (c), (d), (e) and (f) indicate that every calculation for each sensor measurement requires a matrix inversion which will slow down the total tracking process and degrade the track accuracy.

(6) THE MODIFIED MULTI-SENSOR TRACK FUSION MODEL(U):



(A) MULTI-SENSOR CORRELATION PROCESSOR:

The correlation coefficient between feature target vectors X_I and X_q can be expressed as follows:

$$R(X_i,X_q) = \Sigma(j=1,n)\ \{ 1.0/ X_{\bullet j}\} * \left(\left| X_{ij} / X_{j\bullet}) - (X_{qj} / X_{q\bullet}) \right|^2 \right.$$

$$\text{Where } X_{\bullet j} = \Sigma(i=1,n)\ X_{ij} /n$$

$$X_{j\bullet} = \Sigma(q=1,n)\ X_{jq} /n$$

(B) 1, POSITION UPDATE ALGORITHM:

$$X_{k+1} = X_k + \alpha * (X_k - X_{k-1})$$

2, VELOCITY UPDATE ALGORITHM:

$$V_{k+1} = V_k + T* A_k + (\beta/ q * T)*[X_k - X_{k-1}]$$

3, ACCELERATION UPDATE ALGORITHM:

$$A_{k+1} = A_k + \{\gamma/(q * T)^2\} * [X_k - X_{k-1}]$$

Tracking processing:

(1) Sensor measurement is obtained from the" Sensor" unit, preprocessing for target feature vectors.

(2) Target feature vector are passed to the "TRK_#k" unit as input vector for target track estimation.

(3) Target track are passed to the "CORR MODEL" unit for track to track correletion, and only the distinct uncorrelated target track is sent to "α,β,γ UPDATE" unit, using the α, β, γ Tracker for track position update and target covariance update.

(4) The updated target tracks are passed to " PVI" unit to build the central track file (CTF), in which the Pilot will get the Multi-Sensor fused target tracks.

(7) THE MULTI-SENSOR CORRELATION PROCESSOR:

The purpose of Multi-Sensor correlation processor is to measure the Similarity or Dissemblance of two target vectors X and Y. For similarity measure, the Coefficient of Correlation is one if target X is the same as target Y. For dissemblance measure, the Coefficient of Correlation is zero if target X is the same as target Y.

There are many forms of Multi-sensor correlation processors, some of them are base on The similarity measure and others are based on the dissemblence measure. We pick The Bensecri Correlation Model as the Multi-sensor correlation processor for the modified Multi-sensor track fusion model. The Bensecri correlation model is one of the dissemblence Measure.

Mathematically, the Multi-sensor correlation processor can be defined as follows:

Given $X_i = \{ x_{i,1}, x_{i,2}, \ldots\ldots\ldots x_{i,,k}\}$ **as feature target from sensor A**
$X_q = \{ x_{q,1}, x_{q,2}, \ldots\ldots\ldots x_{q,,k}\}$ **as feature target from sensor B**

The correlation coefficient between feature target vectors X_I **and** X_q **can be expressed as follows:**

$$R(X_i, X_q) = \Sigma(j=1,n) \{ 1.0 / X_{\bullet j}\} * \left(\left| X_{ij} / X_{j\bullet}) - (X_{qj} / X_{q\bullet}) \right|^2 \right. \text{---------------(A)}$$

Where $X_{\bullet j} = \Sigma(i=1,n)\, X_{ij} / n$
$X_{j\bullet} = \Sigma(q=1,n)\, X_{jq} / n$

The correlation coefficient has value of zero, if X_I **and** X_q **are identical, and has a positive number greater then zero if they are different targets. Mathematically, the property of the correlation coefficient can be expressed as follows:**

$$0.0 <= R(X_i\, X_q) <= k$$

Where k is a positive integer.

Equation (A) indicates that there is no matrix inversion for every measurement, if this Multi-sensor correlation processor is used in the modified Multi-sensor track fusion model. Equation (A) replaces the Gating algorithm in the existing Multi-sensor track fusion model.

(8) THE α, β, γ TRACKER:

Mathematical model for the α, β, γ **tracker can be defined as following:**

A , Position Update Algorithm:

$$X_{k+1} = X_k + \alpha * (X_k - X_{k-1})$$

B, Velocity Update Algorithm:

$$V_{k+1} = V_k + T^* A_k + (\beta / q * T)*[X_k - X_{k-1}]$$

C, Acceleration Update Algorithm:

$$A_{k+1} = A_k + \{\gamma/(q * T)^2\} * [X_k - X_{k-1}]$$

Where α, β, γ are fixed coefficients filter parameters.

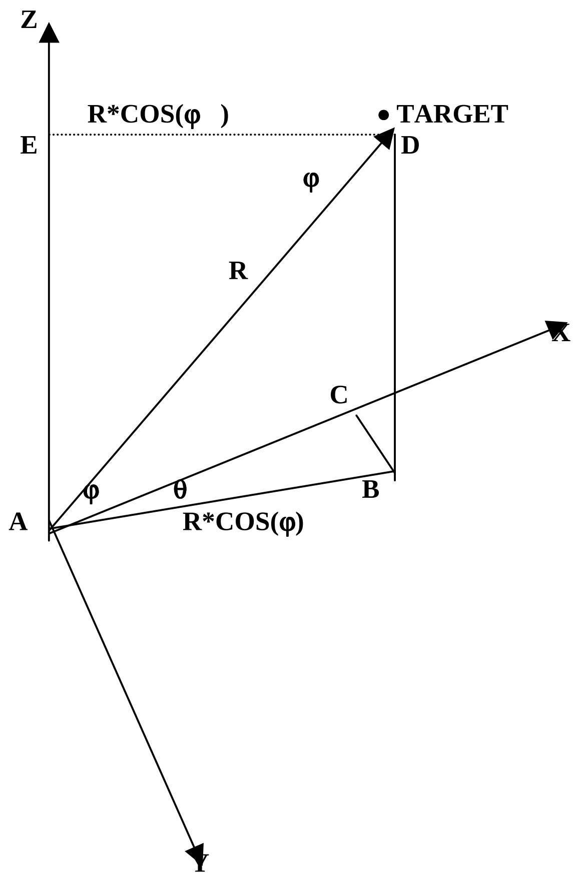
q = number of scant =1.0
T = Sample Interval = 1.0/F
X_{k+1} = Target position at time (k+1)
V_{k+1} = Target Velocity at time (k + 1)
A_{k+1} = Target Acceleration at time (k+1)
K = 1,2,3,…..N
X_{-1} = 0.
X_0, V_0, A_0 are initial values.
$\beta = 2 * (2 - \alpha) - 4 * \text{sqrt}(1 - \alpha)$
$\gamma = \beta^2 / (2 * \alpha)$
If $\alpha = 0.6$, Then $\beta = 0.3$, and $\gamma = 0.08$.

The α, β, γ tracker is one of the widely used trackers, and it is a most algorithmic simple tracking model. In Paul R. Kalata's paper , he had shown some of the tracking parameters are mathematically equivalent to the Kalman Tracker.

(9) THE RANGE & ANGLE TRANSFORMATION:

Normally radar sensor has four feature elements ; range, range rate, az and el as an output vector, and tracker normally has output with position, velocity and acceleration in x,y,z directions. Therefore the objective of the range & angle transformation is to simulate the Extended Kalman Tracker with a set of equations X, Y and Z as a function of range (R), az (φ), and el (θ).

Graphically, if we use NORTH, EAST and DOWN convention, we have:



From triangle ∠ ACB, We have:

$X = AC = R*COS(\varphi)* COS(\theta)$ ---------------(a)

$Y = BC = R*COS(\varphi)* SIN(\theta)$ -------------- (b)

From triangle ∠AED, We have:

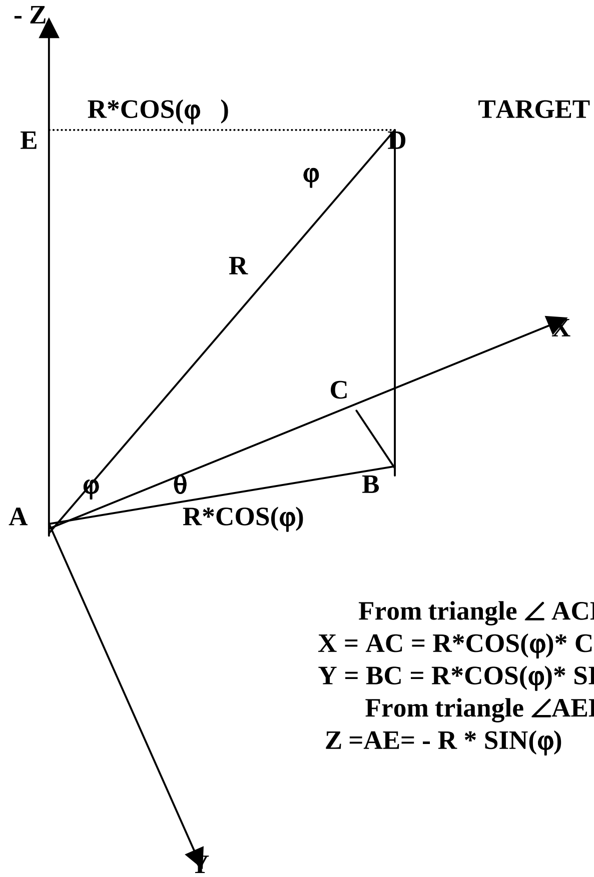
$Z = AE = - R * SIN(\varphi)$ --------------- (c)

Equations (a),(b) and (c) are the required result of the range and angle transformation.

(10) THE X,Y,Z TRANSFORMATION:

Normally radar sensor has four feature elements ; range, range rate, az and el as a output vector, and Tracker normally has output with position, velocity and acceleration in x,y,z directions. Therefore the objective of X,Y,Z transformation is to simulate the radar sensor and obtained a set of equations R, φ and θ as a function of X,Y,Z .

Graphically, if we use North, East, Down convention and we have:



From triangle ∠ ACB, We have:

$X = AC = R*COS(\varphi)* COS(\theta)$ ---------------(a)

$Y = BC = R*COS(\varphi)* SIN(\theta)$ -------------- (b)

From triangle ∠AED, We have:

$Z = AE = - R * SIN(\varphi)$ --------------- (c)

From (a), (b) and (c), We have:

$R = SQRT(X^2 + Y^2 + Z^2)$ ---------------- (d)

From (a) and (b), We have:

$\theta = \tan^{-1}(X / Y)$ ----------------(e)

From (c), We have:

$\varphi = - SIN^{-1}(Z / R)$ ----------------(f)

Range_ rate can be obtained from equation (d) by differentiating the Range with respect to time, and Range_rate = $(X * V_x + Y* V_y + Z * V_z) / R$ ----------------(g)

Equations (d), (e), (f) and (g) are the required result of the X, Y and Z transformation.

(11) SIMULATIONS:

A simulation using three targets and one ownship was conducted at an update rate of 1.0 Hz for a period of 120 seconds for the existing Multi-sensor track fusion model. The tracking errors were below 4.0% for all cases, but 120 seconds is considered too slow for fast moving targets. Currently, we are working with the modified Multi-

sensor track fusion model, and expect the time to be faster, because the modified Multi-sensor track model requires no matrix inversion for every sensor measurement.

(a) TARGET MODELS:

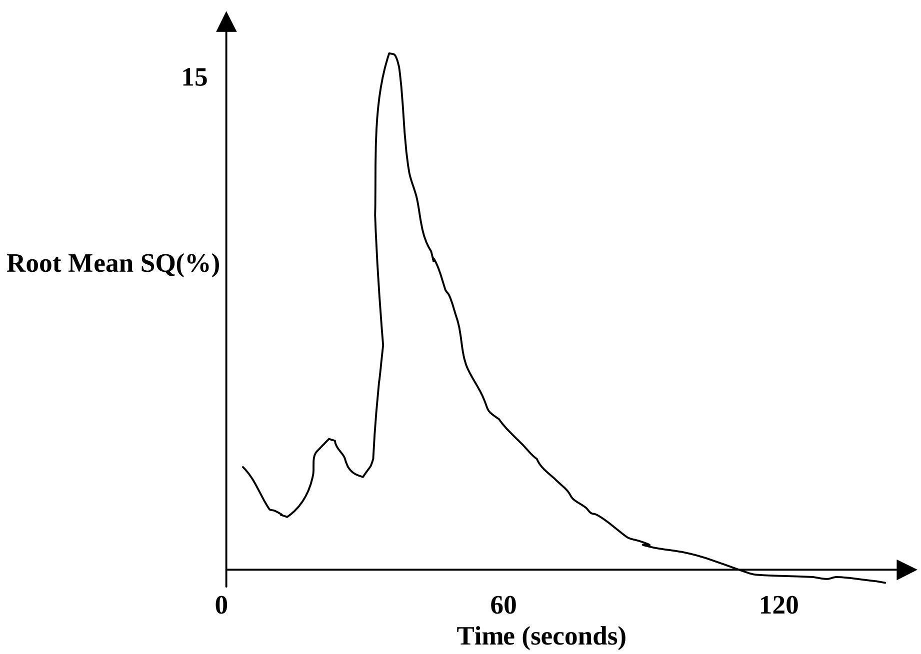
T1: $X1(t) = a * t^2 + b * t + c$
where $a = 0.01$, $b = 0.02$, $c = 3.0$

T2: $X2(t) = a * t + b$
Where $a = 1.5$, $b = 1.0$

T3: $X3(t) = a * (1.0 - e^{-b*t}) + c$
Where $a = 300.0$, $b = 0.0005$, $c = 1.0$

Ownship: $X0(t) = a * t + b$
Where $a = 0.5$, $b = 30.0$

(b) TRACKING ERRORS:



(12) CONCLUSIONS:

(a) Theoretically, the Modified Multi-Sensor Track Fusion Model is the most algorithmically simple compared to the existing Multi-Sensor Track Fusion model. The α, β, γ tracker in the modified Model is much easy to implement compared to the Extended Kalman Tracker in the existing Model. The Multi-Sensor Correlation Processor in the modified Model is mathematically

Simple compared to the Gating Model in the existing Model

(b) Matrix inversion is required for every sensor measurement in the Gating Model, position state vector update algorithm, and covariance matrix update algorithm of the existing Multi-sensor track fusion model. Every matrix inversion takes a lot of time, and computer memory resource. This alone will slow down the total tracking time and track accuracy.

(c) There are no matrix inversions for every sensor measurement in the Multi-Sensor correlation processor, and in the α, β, γ Tracker of the Modified Multi-Sensor Track Fusion Model. This is a mathematically an advantage over the existing Multi-Sensor Track Fusion Model.

(d) The performance and track accuracy of the Tracker, depends on the target noise, filter parameters, and constant coefficients. Dr. Paul R. Kalata has published a paper in the IEEE, which shows that the α, β, γ Tracker yields similar and consistent results when compared with the Kalman Tracker.

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